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A team of ten Ph.D. scientists and several graduate students has been assembled at USU to work in close collaboration with scientists at the Air Force Geophysics Laboratory on a number of problems that are relevant to Air Force systems, including OTH radars, communications, and orbiting space structures. The overall goal of the research is to obtain a better understanding of the basic chemical and physical processes operating in the geoplasma environment, including the ionosphere, thermosphere, and magnetosphere. Some of our specific tasks include the following: (1) Studies of ionospheric structure and irregularities; (2) Study the feasibility of developing better operational ionospheric models; (3) Conduct model/data comparisons in order to validate the ionospheric models; (4) Study plasma electrodynamics in the high latitude ionosphere; (5) Study magnetosphere-ionosphere coupling problems; (6) Continue the development of our thermospheric circulation model; (7) Study plasmasphere refilling problems; (8) Study OTH ray tracing problems at high latitudes; and (9) Study certain spacecraft-environment interaction problems, including those related to high-voltage power sources, spacecraft outgassing, artificial plasma cloud expansion, and spacecraft charging at LEO altitudes.

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1 JUN 1992

Annual Technical Report

# USU Center of Excellence in Theory and Analysis of the Geo-Plasma Environment

By: R.W. Schunk
Center for Atmospheric and Space Sciences
Utah State University
Logan, Utah 84322-4405

For: Department of the Air Force
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Bolling Air Force Base
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# 1. INTRODUCTION

A team of ten Ph.D. scientists and several graduate students has been assembled at USU in order to establish a 'Center of Excellence in Theory and Analysis of the Geo-Plasma Environment.' The USU scientists work in close collaboration with colleagues at the Phillips Laboratory (PL) in Bedford, Massachusetts, on a number of problems that are relevant to Air Force systems, including OTH radars, communications, and orbiting space structures. The overall goal of the research is to obtain a better understanding of the basic chemical and physical processes operating in the geoplasma environment, including the ionosphere, thermosphere, and magnetosphere. Some of the more specific goals are as follows:

1. Study the production, transport and decay of ionospheric density structures. This will include studies of the main electron density trough, sun-aligned arcs, and plasma blobs.

2. Assist in the development of better operational ionospheric models for the Air Force. This includes running our numerical model of the global ionosphere for numerous geophysical cases so that the results can be incorporated into the AWS *Ionospheric Specification Model.*

3. Conduct model/data comparisons in order to validate the ionospheric models.

4. Develop a ray tracing code for our global ionospheric model so that we can support PL's OTH radar campaigns.

5. Explore methods of incorporating the PL particle precipitation energy index in both magnetospheric convection and particle precipitation models, which are inputs to the ionospheric and thermospheric specification models.

6. Study plasma convection characteristics at high latitudes with emphasis on northward interplanetary magnetic field (IMF) conditions.

7. Study magnetosphere-ionosphere coupling problems, including wave excitation associated with the polar wind and energetic ion outflows. We will also study the electrical coupling and currents in the magnetosphere-ionosphere system.

8. Continue the development of a high-resolution multi-species thermospheric circulation model. This is relevant to AWS's interest in developing a real-time *Thermospheric Specification Model.*

9. Study plasmasphere refilling characteristics associated with magnetic storms and substorms.

10. Study certain spacecraft-environment interaction problems, particularly those related to solar cell changing, high-voltage power sources, artificial plasma cloud expansion, and outgassing from large structures orbiting at ionospheric altitudes.

## 2. USU-PHILLIPS LABORATORY COLLABORATIVE EFFORTS

At the present time, we have ongoing collaborative efforts with several scientists at the Phillips Laboratory in Bedford, Massachusetts. In the paragraphs that follow, we briefly describe the progress made during the last year.

### 2.1. *D. Anderson* (LIS) →

We helped D. Anderson develop a *High Latitude Ionospheric Specification Model* for Air Weather Services. Our original effort involved running our numerical ionospheric model for both the northern and southern hemispheres for a range of solar cycle, seasonal, magnetic activity, and IMF conditions. A total of 108 ionospheric simulations were run. R. Daniell of Computational Physics Incorporated (CPI) 'fit' our calculated density distributions as a function of altitude, latitude, longitude, season, solar cycle, magnetic activity, and universal time using relatively simple functions. These background density distributions were then incorporated into his Parameterized Real-Time Ionospheric Specification Model (PRISM). During the last year, D. Anderson requested that we determine the accuracy of the fitting procedure and D. Crain in our group undertook this effort. D. Crain found that the parameterized model developed by R. Daniell reproduced the original density distributions very well and that the parameterized version of our numerical ionospheric model was much more representative of the high-latitude ionosphere than existing models.

At the request of D. Anderson, J. Sojka is spearheading an inter-model comparison of the noon sector mid-latitude *F* region. This inter-model comparison, PRIMO, is a CEDAR activity but is, to a large extent, the outgrowth of USU-PL interactions in ionospheric model and data comparisons. The problem being focussed on in this research area is the difficulty during solar maximum conditions of reproducing the observed $N_mF_2$ values. The models are generally too low. A presentation of these results was made at the CEDAR 1991 meeting.

### 2.2. *S. Basu* (LIS) →

In collaboration with S. Basu and C. Valladares (Boston College) we studied the properties of sun-aligned arcs. In one effort, the emphasis was on the ionospheric modification caused by a typical sun-aligned polar cap arc. The radar, optical, and satellite data pertaining to these arcs that were available at Phillips Laboratory were used to define the arc features and our ionospheric model was then run using these parameters to elucidate the ionospheric response to the arc. A paper describing this work is currently being written.

### 2.3. *H. Carlson* (LIS) →

At the beginning of this year's effort, H. Carlson emphasized the need to understand the electrodynamics of a sun-aligned polar cap arc. He was interested in understanding how the system self-consistently evolves from a fairly uniform ionosphere to a polar cap arc situation. He was also interested in determining what contribution the *F* region ionization makes to the overall conductivity of the sun-aligned arc. In response to these interests, L. Zhu initiated the development of a time-dependent model of a sun-aligned arc in which the electrodynamics are treated self-consistently in the frame of the magnetosphere-ionosphere system. The model development was completed during the last year and the model is currently being used to study the temporal development and evolution of an arc driven by magnetospheric processes.

2.4. *W. Denig* (PHG) →

The very strong geomagnetic storm of 13 March 1989 has been the focus of a close collaboration with Dr. W. Denig. The first draft of the publication is well in hand. The extensive DMSP data base for this March 1989 period has been interpreted by W. Denig and used both as an input data set to our global ionospheric model, and as an in situ plasma density reference data set to compare against the model results. The pre-storm observation and model agreement is good. During the storm phase the comparisons are very good. Both DMSP and TEC data were used for the comparisons.

2.5. *J. Klobuchar* (LIS) →

In conjunction with J. Klobuchar at Phillips Laboratory and P. Doherty at Boston College, we began a study of the TEC variation observed at various high-latitude stations compared to those predicted by our ionospheric model. Specifically, TEC values predicted by our time-dependent ionospheric model were compared with the diurnal variations of TEC measured at the Goose Bay, Hamilton Bay, and Poker Flat observing sites and, in general, very good agreement between model and data was achieved. A paper on this comparison is currently being written.

2.6. *Drs. D. Hardy and S. Gussenhoven* (PHP) →

Captain T. Frooninckx completed his Masters Degree at USU in the spring of 1991 [*Frooninckx,* 1991]. His thesis concerned the spacecraft charging experienced on the DMSP satellites. Captain Frooninckx worked with scientists at the Phillips Laboratory, specifically, Drs. D. Hardy and S. Gussenhoven. As a result of this work, a strong solar cycle dependence in the spacecraft charging was postulated and verified using the DMSP data. Two papers were written and submitted, one has now been published (papers 30 & 35).

2.7. *J. Buchau* (LIS) →

In support of J. Buchau's OTH radar work, Captain P. Citrone has interfaced our time-dependent, high-resolution ionospheric model with the *Jones and Stephenson* [1975] ray-tracing program to examine the effects of 3-D electron density gradients on ray propagation. We have carried out initial validation tests of the ray paths through this ionosphere. These tests indicated an azimuthal position bias as the ray paths are bent by horizontal electron density gradients. Work is underway to simulate ionospheric conditions for a PL-OTH campaign. The potential value of this physical model is that it can generate physically realistic ionospheric conditions, which can be used as a reference for ray-tracing simulations on a specific day, time, and location. In situ data can then be used to modify or add fine structure as appropriate. Or, in the absence of data, parametric sensitivity studies can readily be carried out. For his M.S. thesis, P. Citrone studied the effect of the trough-auroral boundary on the propagation and bending of HF radio waves.

2.8. *D. Cooke* (PHK) →

We are studying a range of spacecraft-environment interaction problems that are relevant to D. Cooke's interest. These include outgassing from the Space Shuttle, the expansion of artificial plasma clouds, solar cell charging processes, and high-voltage spheres in the ionosphere. Several papers have been written on these topics during the last year and these are briefly described in the next section and listed in the URI Publications section.

2.9. *J. Whalen* (LIS) →

J. Sojka met with J. Whalen during his July 19, 1991 visit to Hanscom Air Force Base. They discussed J. Whalen's recent work on the extensive IGY ionosonde data base, which covers both the northern and southern hemispheres. They discussed, at some length, his equinox data, which show the same $K_p$ dependence for the afternoon sector troughs in the northern and southern hemispheres. Indeed, the conjugacy is remarkably strong considering the various shortcomings in global coverage and available days in the equinox periods during IGY. We discussed a joint follow-up to this work using the USU northern and southern hemisphere computer simulations that were run for D. Anderson (the 108 simulations).

J. Whalen has also been looking at the stations in the polar cap which, during winter conditions, see a peak density at magnetic noon rather than geographic (solar) noon. This maximum is a convection feature. He has data from up to 5 stations at different longitudes but at the same magnetic latitude (~75°) in the southern hemisphere. Each has a distinctly different solar - magnetic noon offset and each shows the magnetic noon peaking. These data relate to the phenomenon referred to as the "tongue of ionization." This work is at an early stage, but we are interested in following up with an ionospheric model study and a subsequent comparison with his data to see if our ionospheric model properly describes the 'tongue' feature.

## 3. AWS PERSONNEL

Four Air Force personnel from Air Weather Services have completed their M.S. Theses during the last two years. Their names, theses titles, major professors, and completion years are listed below.

1. Gary R. Huffines
   Title: Using the USU Ionospheric Model to Predict Radio Propagation Through a Simulated Ionosphere
   Date: 1990
   Major Professor: Jan J. Sojka

2. Thomas B. Frooninckx
   Title: High-latitude Spacecraft Charging in Low-Earth Polar Orbit
   Date: 1991
   Major Professor: Jan J. Sojka

3. David R. Payne
   Title: Electron Heating and Ion Production Rates in Auroral and Sun-Aligned Arcs
   Date: 1991
   Major Professor: Robert W. Schunk

4. Peter J. Citrone
   Title: The Effect of Electron-Density Gradients on Propagation of Radio Waves in the Mid-Latitude Trough
   Date: 1991
   Major Professor: Jan J. Sojka

In addition, two new Air Force students, W. Cade and M. Loveless, have recently joined our group and will begin working on research topics for their M.S. theses in the Fall.

# 4. SCIENTIFIC ACCOMPLISHMENTS

In addition to the USU-PL collaborative efforts that are in progress, we have also completed a number of additional studies. During the second year of the URI program, *17 scientific papers* have been submitted for publication, *21 presentations* have been given at both national and international meetings, and there have been several trips to the Phillips Laboratory in Boston, Massachusetts and to AWS in order to coordinate activities. Lists of the URI personnel, publications, presentations, and trips are attached.

In the subsections that follow, we briefly highlight *some* of the scientific accomplishments and discuss the status of work in *some* of the important areas. The emphasis during the second year of our URI program was on spacecraft-environment interaction studies, including spacecraft charging (papers 30 & 35), high voltage spheres (papers 21, 23, & 26), arc discharging of solar arrays (paper 27), and artificial plasma cloud expansion (paper 31).

## 4.1 *Spacecraft Charging*

Spacecraft charging of Air Force satellites can lead to serious operational anomalies and, hence, this area of research has direct and practical applications. Most of the charging occurs along geosynchronous orbits as the satellites encounter the energetic particles in the radiation belts, but recent experimental evidence has shown that satellites in low-earth-orbit can also charge to significant potentials. In particular, experimental evidence clearly indicates that Defense Meteorological Satellite Program (DMSP) polar orbiting spacecraft at 840 km can develop electric potentials as severe as –1430 V while at high magnetic latitudes. To explore this charging region, an analysis of DMSP F6, F7, F8, and F9 satellite precipitating particle and ambient plasma measurements taken during periods of high, medium, and low solar flux was performed. One hundred eighty-four charging events ranging from –46 to –1430 V were identified, and an extreme solar cycle dependence was found, as charging is most frequent and severe during solar minimum. Satellite measurements and time-dependent ionospheric model (TDIM) output were used to determine the cause of the solar cycle dependence and to characterize the environments which both generate and inhibit these potentials. The electron precipitation associated with various DMSP charging levels was analyzed; it was suggested that precipitating electrons as low as 2 to 3 keV may contribute to charging, although higher-energy electrons make greater contributions. Secondary electron production due to incident electrons below 1 keV was shown to inhibit charging. The energetic electron fluxes shown to generate charging did not vary significantly over the solar cycle. Instead, DMSP ambient plasma data and TDIM generated results indicated that a variation in the thermal plasma density of over 1 or more orders of magnitude was the cause of the solar cycle dependence, and an ambient plasma density of less than $10^4$ $cm^{-3}$ was found necessary for significant negative charging ($\geq 100$ V) to occur.

### 4.2 *Artificial Plasma Cloud Expansion*

We conducted three-dimensional simulations of the expansion of artificial plasma clouds in the ionosphere at low-earth-orbit (LEO) altitudes (paper 31). Such clouds can be created by spacecraft outgassing followed by ionization or by the direct injection of a neutral gas into the ionosphere. In the study, a 3-dimensional, time-dependent fluid model was used to study the ionization and plasma expansion characteristics of barium clouds. Neutral gas clouds with a total mass of 1 kg were released with a spherical Gaussian density distribution and the subsequent photoionization by solar UV radiation and ion cloud expansion were modelled. Three cases were considered: A cloud without a directional velocity; a cloud with an initial velocity of 5 km/s across the $\vec{B}$ field; and a cloud with initial velocity components of 2 km/s both along and across the $\vec{B}$ field. For the cloud without a directional velocity, the ionization occurs in a spherical volume. The resulting $Ba^+$ cloud expands along the $\vec{B}$ field and the $Ba^+$ density distribution gradually becomes ellipsoidal from the inner to the outer parts of the $Ba^+$ cloud. The electrostatic snowplow effect associated with the expanding $Ba^+$ cloud creates a hole in the $O^+$ background at the center of the $Ba^+$ cloud and creates two $O^+$ density bumps on the two sides of the $Ba^+$ cloud. For the neutral gas release with an initial velocity across the $\vec{B}$ field, the resulting $Ba^+$ cloud has a comet-like density distribution at early times. Eventually, because of the expansion along the $\vec{B}$ field, the $Ba^+$ cloud becomes sheet-like. Again, there are two $O^+$ density enhanced regions and one $O^+$ density depletion region in the background ionosphere. For these two cases, although there are $O^+$ density depletions, there are no electron density (total plasma) depletions. When the neutral gas cloud has initial velocity components both along and across the $\vec{B}$ field, the situation is quite different. The resulting $Ba^+$ cloud has a complicated density distribution. The $Ba^+$ snowplow effect creates an $O^+$ density hole on one side and an $O^+$ density bump on the other side of the expanding $Ba^+$ cloud. There is a net plasma depletion on the side opposite to the $Ba^+$ cloud motion along the $\vec{B}$ field.

### 4.3 *Solar Cell Operation*

We published one paper that dealt with the interaction of solar cell modules with the ionospheric plasma (paper 27). For future space missions, elevated voltages of hundreds of volts are necessary to minimize mass requirements and resistive losses of orbiting solar arrays. However, these elevated voltages (both negative and positive) can yield hazardous conditions, including anomalous current surges, arcing, and continuous power drains. Most of the work done in the past dealt with 'positive' voltages, but recently there has been an increased interest in 'negative' solar cells. Therefore, we examined both experimental data and particle-in-cell (PIC) computer simulations in order to determine in what region of the solar array is arcing likely to occur. In general, it could occur at the interconnector-dielectric interface, solar cell edge, or gap regions. However, for 'negative' voltages we found, contrary to what was found for positive voltages, that arcing occurs around the gap region between adjacent solar cells and also at the solar cell edge - substrate interface, but not around the negatively biased interconnectors.

### 4.4 *High-Voltage Spheres*

Three of our papers were concerned with the interaction of a high-voltage sphere with the LEO plasma environment (papers 21, 23, & 26). This work was motivated by the fact that high-voltage power sources are being considered for both military and commercial space stations, and the direct interaction of a high-voltage system with the ionospheric plasma could lead to arcing and severe power losses.

In our first study (paper 21), we concentrated on the initial interaction of a biased sphere with a magnetized, partially-ionized plasma that had characteristics similar to those found at shuttle altitudes. Positive potentials were suddenly applied to the sphere and the subsequent response of the plasma was modelled via a numerical solution of the time-dependent, three-dimensional, nonlinear fluid equations for the ions and electrons and the Poisson equation. The main goal of the study was to determine the effect of impact ionization and collisions on the sphere-plasma interaction in the presence of outgassed or released neutrals from the Space Shuttle. Simulations were conducted for different neutral species, a range of neutral densities, as well as different magnetic field strengths. The main conclusions of the study are as follows: (1) When a high-voltage sphere is embedded in a magnetized, partially-ionized plasma, an electron density torus tends to form around the sphere in the equatorial plane at early times. The torus rotates about the sphere in the $\mathbf{E} \times \mathbf{B}$ direction. If the background neutral gas density is sufficiently high, the electrons accelerated by the strong electric fields associated with the sphere can ionize the gas by impact. At a critical ionization rate, a discharge or breakdown occurs. Collisions, on the other hand, act to decelerate the electrons and modify the space charge configuration (i.e., modify the toroidal shape); (2) For low neutral densities ($\leq 5 \times 10^{11}$ cm$^{-3}$), collisions and impact ionization are not important; (3) For neutral densities of the order of $10^{12}$ cm$^{-3}$, ionization occurs in the toroidal region where the electron density is elevated, but this impact ionization does not appreciably affect the current collection. In this case, a toroidal density configuration can be maintained without a discharge and the effect of collisions is to broaden the torus; (4) For neutral densities of the order of $10^{13}$ cm$^{-3}$, the major ionization still occurs in a toroidal region. However, the ionization causes the plasma density and current collection to increase rapidly. A toroidal discharge is expected in this case; (5) For neutral densities of the order of $10^{14}$ cm$^{-3}$, impact ionization occurs all around the sphere in an explosive manner. The discharge is likely to be spherical in this case; (6) The above results are for a magnetic field of 3 gauss. If the magnetic field is reduced and the other parameters are held fixed, the ionization that occurs tends to be more spherical. The current collection also tends to be higher; and (7) Different molecules have different ionization energies, and collision and ionization cross-sections. Of the four species studied, Ar, $N_2$, and O have very similar properties, and hence, the features discussed above for Ar also apply quantitatively for $N_2$ and O. However, barium behaves very differently. It has a larger collision cross-section and lower ionization energy. Therefore, for the same conditions, ionization and discharge processes are much easier to trigger in a Ba plasma. Also, compared to Ar, O, and $N_2$, the density distribution, as well as the discharge, tend to be more spherical.

The other two papers (23 & 26) involved high-voltage spheres embedded in *unmagnetized* plasmas. In one study, a high 'positive' voltage was applied to the sphere and the effect of different potential rise times was investigated as was the long-term evolution of the sphere-plasma interaction. In the other paper, 'negative' voltages were applied to the sphere and the subsequent sphere-plasma interaction was modelled.

From our simulations we found that after the positive voltage is applied to the sphere, the electrons are accelerated toward the sphere in a few plasma periods and an overshoot oscillation usually follows. The acceleration and the density buildup of the electrons around the sphere produce a high current collection by the sphere. This high current level usually lasts a few hundred plasma periods or a few ion plasma periods. Then the ion motion becomes significant. The ions are accelerated away from the sphere and an ion density shell forms and propagates away from the sphere. The ion density shell blocks the electron flow and reduces the current. The deceleration of the electrons by the ion shell leads to an electron density enhancement so that a double layer structure forms. The double layer propagates outwards and eventually slows down and disappears. This process lasts a few thousand plasma periods. During this time, the current first decreases to a minimum and then slowly reaches a constant level. Low frequency oscillations (lower than the ion plasma frequency) may appear due to the overshoot of the ion density configuration about its equilibrium position. However, a steady state is eventually reached.

In the steady state, the ion density satisfies the Boltzmann relation. In some regions near the sphere, the ions are completely depleted and only electrons are present. There is also a region where the ion and electron densities are unequal. The region with a net space charge is the sheath region. This region can be comparable to or larger than the sphere radius, depending on the applied voltage. The sheath thickness estimated from the electron and ion density profiles agrees with the Langmuir-Blodgett theory. Far away from the sphere, the plasma is unperturbed. Between the sheath region and unperturbed plasma is the presheath, where there is no net space charge, but both the electron and ion densities differ from the unperturbed value. The thickness of the presheath increases with higher applied voltages. The current density from the simulation is 2 to 5 times higher than that from the simple Langmuir-Blodgett theory.

The method of applying the voltage on the sphere affects the temporal evolution. If the voltage is applied according to an exponential law with a rise time $\tau$, only the electron motion at very early times is affected if $\hat{\tau} \leq 1$. For $\hat{\tau} = 0.1$, the result is almost identical to the result for $\hat{\tau} = 0$ (a step function application of the voltage). For $\hat{\tau} = 1.0$, the electron density and velocity near the sphere are lower than those for $\hat{\tau} = 0$ or 0.1 before five plasma periods, and so is the current. Afterwards, the results are the same. For $\hat{\tau} = 10$, there are several differences. The acceleration of the electrons is much lower. The overshoot oscillation at early times does not occur. The ion motion is affected. The formation of the density shell is delayed. For different $\hat{\tau}$'s, the system reaches the steady state in slightly different ways. For a small $\hat{\tau}$, the ion density configuration may pass the final equilibrium location and oscillate about it. For a large $\hat{\tau}$, such an overshoot oscillation is more likely.

In our paper dealing with high 'negative' voltage spheres, simulations were conducted for a range of voltages (–10 to –10,000 V) and for plasma densities from $10^4$ to $10^6$ cm$^{-3}$. The temporal evolution of the plasma was followed all the way to the steady state. In all simulations, there were certain qualitative similarities in the plasma response. At very early times, the rapid electron motion away from the sphere resulted in an electron overshoot oscillation (ringing). The frequency of this oscillation was a fraction of the electron plasma frequency and increased slowly with the magnitude of the voltage on the sphere. For high plasma densities, the oscillation was damped as the initial ion current surge to the sphere developed. Subsequently, the ion current reached a peak, decreased, and then attained a steady-state level. The final sheath and presheath sizes for negative-voltage spheres were similar to positive-voltage spheres with the same potential magnitude, although the temporal evolution of the plasma was different for positive and negative spheres. In the steady state and for a given plasma density, the ion density structure in the sheath varied with the applied voltage on the sphere. As the voltage increased, an ion density hole developed around the sphere in the sheath region. Near the sphere the ion density was relatively high, but the ion density decreased with distance, reached a minimum, and then increased to the background value. For a –10,000 V sphere, the ion density near the sphere was also four times larger than the background plasma density.

### 4.5 *Magnetosphere – Ionosphere Coupling via Electric Fields*

It is well known that the electric fields, particle precipitation, auroral conductivity enhancements, and Birkeland currents that couple the magnetosphere-ionosphere system are strongly dependent upon the direction of the IMF. When the IMF is southward, the Birkeland (or field-aligned) currents flow in the Region 1 & 2 current sheets, the *F* region plasma convection exhibits a 2-cell structure with antisunward flow over the polar cap, the conductivity enhancements are confined to the statistical auroral oval, and the auroral electron precipitation is also confined to the classical oval. However, when the IMF is northward, the situation is considerably more complicated and less clear. In this case, an additional field-aligned current system occurs in the polar cap called the NBZ currents; plasma convection can be sunward in the polar cap and the pattern can assume multi-cell, severely distorted two-cell or turbulent characteristics; and particle precipitation occurs in the polar cap that can be uniform, in the form of multiple sun-aligned arcs, or in a $\theta$-aurora configuration.

We have been and are continuing to conduct several theoretical studies in an effort to elucidate the ionosphere-magnetosphere coupling processes during northward IMF. One of our efforts involved the use of our electrodynamic model to investigate the 'large-scale' field-aligned currents that exist in the polar cap during northward IMF (papers 24 & 34). With our electrodynamic model, we solve Ohm's law and the current continuity equation so as to obtain self-consistency between the ionospheric conductivity, field-aligned current, horizontal E-region current, and convection electric field. In one effort, we used the USU conductivity model and conducted a systematic study of the influence of the ionospheric conductance on the form of the field-aligned current associated with the Heppner-Maynard 'distorted two-cell' convection pattern (paper 24). Our modelling results indicated that, contrary to previous claims, the NBZ current can be associated with the distorted two-cell convection pattern for most of the ionospheric conductivity conditions. We found that the seasonal and auroral activity conditions significantly affect the ionospheric conductivity and that the conductivity variations can influence the basic features of the NBZ current system associated with the distorted two-cell convection pattern. Based on these results, we suggested that the field-aligned current system observed by the MAGSAT satellite might imply a distorted two-cell convection pattern, and that a four-cell pattern is more likely to occur when the IMF is due north or very close to the north.

### 4.6 *Magnetosphere – Ionosphere Coupling via Ion Outflow*

The outflow of thermal plasma from the topside ionosphere at high latitudes (i.e., the polar wind) is very important because the escaping thermal plasma drains the ionosphere and mass - loads the magnetosphere. However, it is difficult to model the outflow because the polar wind is collision-dominated at low altitudes, passes through a transition region, and then becomes collisionless at high altitudes. Over the years, various mathematicals have been used to describe the outflow (hydrodynamic, collisionless kinetic, generalized transport, etc.), but the different models have limitations, particularly in the transition region from collision-dominated to collisionless flow. In an effort to better understand the strengths and limitations of the various models, we have continued our effort whereby different mathematical models are used for the same polar wind conditions so that a direct comparison of results can be made.

During the last year we completed three papers dealing with the validity of the various mathematical models of the polar wind and related flows (papers 20, 25, & 32). In one study (paper 25), we compared, in as consistent a manner as possible, solutions to the bi-Maxwellian-based 16-moment set of transport equations with those obtained from a semikinetic model, assuming boundary conditions characteristic of both supersonic and subsonic flows in the terrestrial polar wind as well as supersonic flow in the solar wind. For each case in which transport and semikinetic solutions were compared, three separate semikinetic solutions were generated. These three semikinetic solutions assumed the particle distribution function at the baropause to be an isotropic Maxwellian, a bi-Maxwellian, and a bi-Maxwellian-based 16-moment expansion with zero stress, respectively. Our study demonstrated several important points: (1) For supersonic "collisionless" flows, the 16-moment transport theory and the semikinetic model assuming a 16-moment distribution at the baropause are almost identical in their predictions, even for the higher-order moments (parallel and perpendicular heat flows). This is true for both polar and solar wind conditions. (2) The semikinetic solutions assuming either a Maxwellian or a pure bi-Maxwellian at the baropause also show extremely close agreement with the transport results for the lower-order moments (density, drift velocity, and parallel and perpendicular temperatures), but are less accurate in their heat flow predictions. (3) The nearly precise agreement between the 16-moment transport solutions and the semikinetic solutions with a 16-moment distribution at the boundary, which implicitly contain the full hierarchy of moment equations, indicates that moments higher than heat flow (flow of parallel and perpendicular thermal energy) are not needed to describe the steady-state polar and solar wind cases considered in this study. (4) Because of its underlying assumptions, the semikinetic model is unable to properly describe subsonic $H^+$ flows. Therefore, a comparison of semikinetic and transport models for subsonic flow conditions must await future advances in the kinetic theory. (5) Collisions are clearly of importance in determining the thermal and heat flow structure of the solar wind. The 16-moment transport model, which incorporates the effects of Coulomb collisions, yields temperature anisotropies at 1 AU that are in agreement with measurements, while the semikinetic model, which is collisionless, does not.

## 5. FUTURE DIRECTION

During the third year of the program, we will continue our collaborative projects with the various scientists at the Phillips Laboratory in Bedford, Massachusetts. We will also continue research in the following general areas:

1. Ionosphere Structure Modelling
2. Operational Ionospheric Models
3. Model/Data Comparisons
4. OTH Radar Studies
5. Direct Magnetospheric Monitoring Index
6. Plasma Convection Studies
7. Magnetosphere-Ionosphere Coupling
8. Thermospheric General Circulation Modelling
9. Plasmasphere Dynamics
10. Spacecraft-Environment Interaction Studies

# URI Personnel

## Ph. D. Scientists

R.W. Schunk - P.I.
J.J. Sojka
A.R. Barakat
D.J. Crain
H.G. Demars
T.-Z. Ma
W.J. Raitt
H. Thiemann
W.-H. Yang
L. Zhu

## Graduate Students

I. Barghouthi
P.-L. Blelly
A. Khoyloo
L. Zhou
W. Cade - AWS
P. Citrone - AWS [Completed Degree Requirement]
G. Huffines - AWS [Completed Degree Requirement]
M. Loveless - AWS
T. Frooninckx - AWS [Completed Degree Requirement]
D. Payne - AWS [Completed Degree Requirement]

## Programmers

M. Bowline
E. Kluzek

## Administrative Support

J. Folsom
S. Johnson
L. Twede

## URI Publications


1. H.G. Demars and R.W. Schunk, Solutions to bi-Maxwellian transport equations for radial solar wind beyond 28 Rs, *Planet. Space Sci.*, *39*, 435–451, 1991.

2. H. Thiemann, R.W. Schunk, and L. Gerlach, Solar arrays in the LEO-plasma environment: A model for leakage current phenomena deduced from experimental and theoretical studies, *Proc. European Space Power Conf.*, *ESA SP-294*, 809–813, 1989.

3. J.J. Sojka, R.W. Schunk, and J.A. Whalen, The longitude dependence of the dayside *F* region trough: A detailed model-observation comparison, *J. Geophys. Res.*, *95*, 15,275–15,280, 1990.

4. H. Thiemann, R.W. Schunk, and K. Bogus, Where do negatively biased solar arrays arc? *J. Rockets & Spacecraft*, *27*, 563–565, 1990.

5. R.E. Daniell, L.D. Brown, D.N. Anderson, J.A. Whalen, J.J. Sojka, and R.W. Schunk, A high latitude ionospheric specification model, *Proc. of the STP Symposium in Australia* , in press, 1990.

6. R.E. Daniell, D.T. Decker, D.N. Anderson, J.R. Jasperse, J.J. Sojka, and R.W. Schunk, A global ionospheric conductivity and electron density (ICED) model, *Proc. of the Ionospheric Effects Symposium*, in press, 1990.

7. R.W. Schunk and E.P. Szuszczewicz, Plasma expansion characteristics of ionized clouds in the ionosphere: Macroscopic formulation, *J. Geophys. Res.*, *96*, 1337–1349, 1991.

8. A.R. Barakat and R.W. Schunk, Effect of $O^+$ beams on the stability of the polar wind, *J. Geophys. Res.*, submitted, 1990.

9. W.-H. Yang and R.W. Schunk, Latitudinal dynamics of steady solar wind flows, *Ap. J.*, *372*, 703–709, 1991.

10. L. Bossy, S. Pallaschke, K. Rawer, R.W. Schunk, J.J. Sojka, and H. Thiemann, High-latitude ionospheric model, *Adv. Space Res.*, *11*, 11–14, 1991.

11. H. Thiemann and R.W. Schunk, Field formation around negatively biased solar arrays in the LEO-plasma, *Adv. Space Res.*, in press, 1991.

12. H. Thiemann, T.-Z. Ma, and R.W. Schunk, High voltage spheres in an unmagnetized plasma: Fluid and PIC simulations, *Adv. Space Res.*, in press, 1991.

13. J.J. Sojka, R.W. Schunk, W.R. Hoegy, and J.M. Grebowsky, Model and observation comparison of the universal time and IMF $B_y$ dependence of the ionospheric polar hole, *Adv. Space Res.*, *11*, 39–42, 1991.

14. R.W. Schunk, Model studies of ionosphere/thermosphere coupling phenomena on both large and small spatial scales and from high to low altitudes, *J. Geomag. and Geoelect.*, in press, 1991.

15. H. Thiemann and R.W. Schunk, Advanced model of solar array-plasma interactions, *Proc. of the ESA Space Environmental Analysis Workshop*, ESA WPP-23, 9 pages, 1990.

16. A.R. Barakat, R.W. Schunk, I.A. Barghouthi, and J. Lemaire, A Monte Carlo study of the transition from collision-dominated to collisionless polar wind flow, *SPI Conf. Proc. and Reprint Series, 10,* 431–437, 1991.

17. W.-H Yang, Expansion of solar-terrestrial low-$\beta$ plasmoid, *Ap. J.*, submitted, 1990.

18. J.J. Sojka and F. Redd, A small satellite constellation for imaging magnetospheric electrodynamics, *Adv. Space Res.*, in press, 1991.

19. R.W. Schunk and J.J. Sojka, Approaches to ionospheric modelling, simulation and prediction, *Adv. Space Res., 12,* 317–326, 1992.

20. H.G. Demars and R.W. Schunk, Comparison of semikinetic and generalized transport models of the polar wind, *Geophys. Res. Lett., 18,* 713–716, 1991.

21. T.-Z. Ma and R.W. Schunk, Ionization in the magnetized ionosphere surrounding a high voltage sphere, *Planet. Space Sci., 39,* 1325–1342, 1991.

22. J.J. Sojka, R.W. Schunk, D. Rees, T.-J. Fuller-Rowell, R.J. Moffett, and S. Quegan, Comparison of the USU ionospheric model with the UCL-Sheffield coupled thermospheric-ionospheric model, *Adv. Space Res., 12,* 89–92, 1992.

23. T.-Z. Ma and R.W. Schunk, High voltage spheres in an unmagnetized plasma: Long term evolution and rise time effects, *Plasma Phys. & Cont. Fusion, 34,* 767–782, 1992.

24. L. Zhu, R.W. Schunk, and J.J. Sojka, Field-aligned current associated with a distorted two-cell convection pattern during northward IMF, *J. Geophys. Res., 96,* 19,397–19,408, 1991.

25. H.G. Demars and R.W. Schunk, Semi-kinetic and generalized transport models of the polar and solar winds, *J. Geophys. Res., 97,* 1581–1595, 1992.

26. T.-Z. Ma and R.W. Schunk, High negative voltage spheres in an unmagnetized plasma: Fluid simulation, *Plasma Phys. & Cont. Fusion, 34,* 783–799, 1992.

27. H. Thiemann and R.W. Schunk, Arc discharges at negatively biased solar arrays, *Proc. of the ESA Space Power Conference*, in press, 1992.

28. J.J. Sojka, Ionospheric physics, *Rev. of Geophys.*, 1166–1186, 1991.

29. E. Szuszczewicz et al., Modelling and measurement of global scale ionospheric behavior under solar minimum, equinoctial conditions, *Adv. Space Res., 12,* 105–115, 1992.

30. J.J. Sojka, T.B. Frooninckx, and R.W. Schunk, Ionospheric control of a unique solar cycle dependence of DMSP spacecraft charging, *Geophys. Res. Lett.*, submitted, 1991.

31. T.-Z. Ma and R.W. Schunk, Ionization and expansion of barium clouds in the ionosphere, *J. Geophys. Res.*, submitted, 1992.

32. H.G. Demars, A.R. Barakat, and R.W. Schunk, Comparison of generalized transport and Monte Carlo models of the escape of a minor species, *J. Atmos. Terr. Phys.*, in press, 1992.

33. W.-H. Yang, Self-similar evolution of magnetized plasmas, 1., Quasi-static solution, *Ap. J.*, submitted, 1992.

34. L. Zhu, R.W. Schunk, and J.J. Sojka, Field-aligned currents, conductivity enhancements, and distorted two-cell convection for northward IMF, *J. Atmos. Terr. Phys.*, in press, 1992.

35. T.B. Frooninckx and J.J. Sojka, Solar cycle dependence of spacecraft charging in low earth orbit, *J. Geophys. Res.*, in press, 1992.

## URI Presentations

1. *W.-H. Yang* and R.W. Schunk, On the source-surface model, AGU Fall Meeting, San Francisco, California; *EOS, 70*, 1254, 1989.

2. *H.G. Demars* and R.W. Schunk, Solar wind proton velocity distributions: Comparison of bi-Maxwellian-based 16-moment theory with observations, AGU Fall Meeting, San Francisco, California; *EOS, 70*, 1263, 1989.

3. *R.W. Schunk*, Modelling the dynamic ionosphere, *Invited Review*, Presented at AGU Fall Meeting, San Francisco, California; *EOS, 70*, 1237, 1989.

4. *T.-Z. Ma* and R.W. Schunk, Expansion of a three-dimensional plasma cloud in the ionosphere, AGU Fall Meeting, San Francisco, California; *EOS, 70*, 1240, 1989.

5. *R.J. Sica*, R.W. Schunk, S.J. Cariglia, M. Buonsanto, J. Holt, and D. Sipler, How well do we really understand the quiet-time mid-latitude ionosphere?, AGU Fall Meeting, San Francisco, California; *EOS, 70*, 1247, 1989.

6. *C.E. Rasmussen*, J.J. Sojka and R.W. Schunk, Modeling of annual variations in plasmaspheric density, AGU Fall Meeting, San Francisco, California; *EOS, 70*, 1247, 1989.

7. *J.J. Sojka*, R.W. Schunk and J.A. Whalen, The longitude dependence of the dayside *F*-region trough: A detailed model-observation comparison, AGU Fall Meeting, San Francisco, California; *EOS, 70*, 1248, 1989.

8. *M.D. Bowline*, J.J. Sojka, R.W. Schunk, J.D. Craven, L.A. Frank, J. Sharber, J.D. Winningham and J.P. Heppner, Dynamics Explorer 1 and 2 data-TDIM study for 22 November 1981, AGU Fall Meeting, San Francisco, California; *EOS, 70*, 1248, 1989.

9. *H. Thiemann* and R.W. Schunk, Simulations of solar array-LEO plasma interactions, AGU Fall Meeting, San Francisco, California; *EOS, 70*, 1249, 1989.

10. *R.W. Schunk* and J.J. Sojka, Temporal variations of the polar wind, AGU Fall Meeting, San Francisco, California; *EOS, 70*, 1249, 1989.

11. *R.E. Daniell*, L. D. Brown, W.G. Whartenby, D.N. Anderson, J.J. Sojka and R.W. Schunk, A parameterized version of the USU high latitude ionospheric model, AGU Fall Meeting, San Francisco, California; *EOS, 70*, 1248, 1989.

12. *D.N. Anderson*, J.A. Whalen, S. Basu, R.E. Daniell, L.D. Brown, W.G. Whartenby, J.J. Sojka and R.W. Schunk, A high latitude ionospheric specification model (HLISM), National Radio Science Meeting, 3-5 January 1990; Boulder, Colorado.

13. *J.J. Sojka* and R.W. Schunk, Ionospheric dependence and sensitivity on the solar EUV flux, Presented at the Quarterly Space Model Development Review Meeting, Peterson Air Force Base, 29 January 1990; Colorado Springs, Colorado.

14. *R.W. Schunk* and J.J. Sojka, Ionospheric variations, *Invited Review*; Presented at the SUNDIAL Workshop, 9-12 April 1990; New Orleans, Louisiana.

15. *R.W. Schunk* and J.J. Sojka, Ionospheric forecast model, Presented at the *Ionospheric Specification Model Quarterly Review*, 14 May 1990; Boston, Massachusetts.

16. *R.W. Schunk* , Model studies of ionosphere-thermosphere coupling phenomena on both large and small spatial scales and from high to low altitudes, *Invited Review*; Presented at the Seventh International Symposium on Solar Terrestrial Physics, 25-30 June 1990; The Hague, The Netherlands.

17. *R.W. Schunk* and J.J. Sojka, Coupled modelling of the ionosphere and thermosphere, *Invited Review*, 28th COSPAR Meeting, 25 June-6 July, 1990; The Hague, The Netherlands.

18. *R.W. Schunk* and J.J. Sojka, Approaches to ionospheric modelling, simulation, and prediction, *Invited Review*, 28th COSPAR Meeting, 25 June-6 July, 1990; The Hague, The Netherlands.

19. *J.J. Sojka* , R.W. Schunk, D. Rees, T. Fuller-Rowell and R.J. Moffett, Comparison of the USU ionospheric model with the UCL self-consistent ionospheric-thermospheric model, 28th COSPAR Meeting, 25 June-6 July, 1990; The Hague, The Netherlands.

20. *E.P. Szuszczewicz*, P. Wilkinson, M.A. Abdu, R.W. Schunk, R. Sica, R. Hanbaba, M. Sands, T. Kikuchi, R. Burnside, J. Joselyn, M. Lester, R. Leitinger, G.O. Walker, B. M. Reddy and J. Sobral, Modelling and measurement of global-scale ionospheric behavior under solar minimum, equinoctial conditions, *Invited Talk*, 28th COSPAR Meeting, 25 June-6 July, 1990; The Hague, The Netherlands.

21. L. Bossy, S. Pallaschke, R. Rawer, R.W. Schunk, J.J. Sojka, and *H. Thiemann*, Combined ionospheric model derived from CCIR and USA data, 28th COSPAR Meeting, 25 June-6 July, 1990; The Hague, The Netherlands.

22. *J.J. Sojka*, R.W. Schunk, W.R. Hoegy, and J.M. Grebowsky, Model and observation comparison of the universal time and IMF dependence of the ionospheric polar hole, 28th COSPAR Meeting, 25 June-6 July, 1990; The Hague, The Netherlands.

23. T.-Z. Ma, R.W. Schunk and *H. Thiemann*, PIC-simulation for the high voltage sphere problem, 28th COSPAR Meeting, 25 June-6 July, 1990; The Hague, The Netherlands.

24. *H. Thiemann* and R.W. Schunk, Electric field formation around negatively biased solar arrays in the LEO plasma, 28th COSPAR Meeting, 25 June-6 July, 1990; The Hague, The Netherlands.

25. *A.R. Barakat* and R.W. Schunk, Polar wind instability due to $H^+$ and $O^+$ beams, Presented at the 1990 Cambridge Workshop in Theoretical Geoplasma Physics on 'Magnetic Fluctuations, Diffusion and Transport in Geoplasmas,' 16-20 July 1990; Cambridge, Massachusetts.

26. *A.R. Barakat*, R.W. Schunk and I. Barghouthi, A Monte Carlo study of the transition layer between the collision-dominated and the collisionless regions in the polar wind; Presented at the 1990 Cambridge Workshop in Theoretical Geoplasma

Physics on 'Magnetic Fluctuations, Diffusion and Transport in Geoplasmas,' 16-20 July 1990; Cambridge, Massachusetts.

27. *R.W. Schunk*, Recent advances in modelling the coupled ionosphere-polar wind system, *Invited Talk*, presented at the 1990 Gordon Research Conference on 'Modeling in Solar Terrestrial Physics', 30 July-3 August, 1990; Plymouth, New Hampshire.

28. *H. Thiemann* and R.W. Schunk, Advanced model of solar array-plasma interactions, ESA Space Environment Analysis Workshop, 9–12 October, 1990; ESTEC, Noordwijk, The Netherlands.

29. *R.W. Schunk* and J.J. Sojka, Simulations of the high-latitude ionosphere for a wide range of conditions, AGU Fall Meeting, San Francisco, California; *EOS, 71*, 1502, 1990.

30. *H. Thiemann* and R.W. Schunk, Electric field formation at solar cell edge regions, AGU Fall Meeting, San Francisco, California, *EOS, 71*, 1506, 1990.

31. *W.-H. Yang* and R.W. Schunk, What the magnetic clouds at IAU infer, AGU Fall Meeting, San Francisco, California, *EOS, 71*, 1519, 1990.

32. *H.G. Demars* and R.W. Schunk, Comparison of generalized transport and kinetic models of the polar wind, AGU FAll Meeting, San Francisco, California, *EOS, 71*, 1493, 1990.

33. *T.-Z. Ma* and R.W. Schunk, Evolution of three-dimensional plasma clouds in the ionosphere, AGU Fall Meeting, San Francisco, California, *EOS, 71*, 1506, 1990.

34. *J.J. Sojka* and R.W. Schunk, F-region's dependence on temporal and spectral structure in the solar EUV flux, AGU Fall Meeting, San Francisco, California; *EOS, 71*, 1482, 1990.

35. *A. Khoyloo*, A.R. Barakat, and R.W. Schunk, Ion plasma flow in the outer plasmasphere: A semi-kinetic model, AGU Fall Meeting, San Francisco, California, *EOS, 71*, 1523, 1990.

36. *I.A. Barghouthi*, A.R. Barakat, J. Lemaire, and R.W. Schunk, $H^+$ outflow in the polar wind: A Monte Carlo study, AGU Fall Meeting, San Francisco, California, *EOS, 71*, 1493, 1990.

37. R.W. Schunk and *J.J. Sojka*, High-latitude ionospheric simulations for a wide range of conditions, presented at the First Annual Conference on Prediction and Forecasting of Radio Propagation at High-Latitudes for $C^3$ Systems, 12–14 February, 1991; Monterey, California.

38. *R.E. Daniell*, L.D. Brown, D.N. Anderson, J.A. Whalen, J.J. Sojka, and R.W. Schunk, High-latitude ionospheric specification model (HLISM), First Annual Conference on Prediction and Forecasting of Radio Propagation at High-Latitudes for $C^3$ Systems, 12–14 February, 1991; Monterey, California.

39. J.J. Sojka, P. Citrone, and *R.W. Schunk*, Simulation of radio wave propagation through a realistically structured ionosphere, First Annual Conference on Prediction

and Forecasting of Radio Propagation at High-Latitudes for $C^3$ Systems, 12–14 February, 1991, Monterey, California.

40. *D.J. Crain,* J.J. Sojka, R.W. Schunk, and P.H. Doherty, A first-principle derivation of the high latitude TEC distribution, AGU Spring Meeting, Baltimore, Maryland; *EOS, 72,* 213, 1991.

41. R.W. Schunk and J.J. Sojka, Dynamic changes in the ionosphere/thermosphere system during major magnetic disturbances, presented on our behalf by *D. J. Crain* at the 20th General Assembly of the IUGG, 11-24 August, 1991; Vienna, Austria.

42. *L. Zhu,* R.W. Schunk, and J.J. Sojka, Influence of the ionospheric conductance on the feature of the field-aligned current associated with a distorted two-cell convection during northward IMF, presented at the 20th General Assembly of the IUGG, 11–24 August, 1991; Vienna, Austria.

43. *A.R. Barakat* and R.W. Schunk, A collisional semi-kinetic model for the polar wind, presented at the 20th General Assembly of the IUGG, 11–24 August, 1991; Vienna, Austria.

44. *T.-Z. Ma* and R.W. Schunk, Ionization in the magnetized ionosphere surrounding a high voltage sphere, presented at the 20th General Assembly of the IUGG, 11–24 August, 1991; Vienna, Austria.

45. *A. Khoyloo,* A.R. Barakat, and R.W. Schunk, On the discontinuity of the semi-kinetic model for plasma flows along geomagnetic field lines, presented at the 20th General Assembly of the IUGG, 11–24 August, 1991; Vienna, Austria.

46. *H.G. Demars* and R.W. Schunk, Comparison of semikinetic and generalized transport models of the solar and polar winds, presented at the 20th General Assembly of the IUGG, 11–24 August, 1991; Vienna, Austria.

47. *H.G. Demars,* A.R. Barakat, and R.W. Schunk, Comparison between 16-moment and Monte Carlo models for outflows in space, presented at the 20th General Assembly of the IUGG, 11–24 August, 1991; Vienna, Austria.

48. *V.B. Wickwar,* J.J. Sojka, and R.W. Schunk, Comparison of observed and modeled electron densities from different regions of the globe, presented at the 20th General Assembly of the IUGG, 11–24 August, 1991; Vienna, Austria.

## URI Travel Summary

1. American Geophysical Union Fall Meeting
San Francisco, California
12/4 - 12/8/89
Schunk, Sojka, Yang, Demars, Ma, Rasmussen, and Thiemann attended meeting and 13 papers were presented.

2. Space Model Development Review Meeting
Peterson Air Force Base, Colorado Springs, Colorado
1/29/90
Schunk and Sojka attended meeting and a joint paper was presented.

3. AFGL Meeting
Boston, Massachusetts
3/12 - 3/13/90
Schunk and Sojka attended meeting to discuss collaborative projects with D. Anderson, F. Marcos and N. Maynard.

4. SUNDIAL Meeting
New Orleans, Louisiana
4/9 - 4/12/90
Schunk attended meeting and presented an invited paper.

5. Ionospheric Specification Model Quarterly Review
AFGL; Boston, Massachusetts
5/14/90
Schunk and Sojka presented talks.

6. CEDAR Workshop
Boulder, Colorado
6/15/90
Sojka was a panel member involving High Latitude Plasma Structures.

7. Solar-Terrestrial Physics Symposium
The Hague, The Netherlands
6/25 - 6/30/90
Schunk presented an invited review talk.

8. COSPAR International Meeting
The Hague, The Netherlands
7/2 - 7/6/90
Schunk, Sojka and Thiemann attended and 8 papers were presented.

9. Cambridge Workshop on Transport in Geoplasmas
Cambridge, Massachusetts
7/16 - 7/20/90
Barakat attended and presented 2 papers.

10. Gordon Research Conference
Plymouth, New Hampshire
7/30 - 8/3/90
Schunk presented an invited talk.

11. AFOSR Supported Research
Boulder, Colorado
8/30 - 9/1/90
D. Payne visited NCAR to discuss the development of an auroral deposition code with Dirk Lummerzheim.

12. AFGL Meeting
Boston, Massachusetts
9/3 - 9/6/90
Schunk and Sojka discussed collaborative efforts with H. Carlson, W. Denig, R. Daniell, D. Hardy, S. Gussenhoven, and J. Whalen.

13. Ionospheric Specification Model Quarterly Review
Scott Air Force Base, Illinois
9/17 - 9/18/90
Sojka attended meeting and presented talk.

14. Pierre-Louis Blelly visit to USU
Logan, Utah
October 1990
To work on a project with R.W. Schunk.

15. AFOSR Supported Research
Boulder, Colorado
11/13 - 11/16/90
D. Payne visited NCAR to compare auroral deposition codes with Dirk Lummerzheim.

16. H. Thiemann visit to USU
Logan, Utah
November - December 1990
To work on several projects with R.W. Schunk.

17. American Geophysical Union Fall Meeting
San Francisco, California
12/2 - 12/7/90
Demars, Khoyloo, Ma, Thiemann, and Yang attended meeting and presented papers.

18. AFOSR Supported Research
Hanscom Air Force Base, Massachusetts
12/11 - 12/19/90
P. Citrone visited the Geophysics Laboratory to collect data and discuss research.

19. Conference on $C^3$ Systems
Monterey, California
2/9 - 2/17/91
Schunk attended meeting and presented two papers.

20. Ionospheric Specification Model Quarterly Review
Colorado Springs, Colorado
3/4 - 3/7/91
J.J. Sojka attended meeting.

21. PRIMO Workshop
Boulder, Colorado
6/20 - 6/21/91
R.W. Schunk and J.J. Sojka attended this workshop which was organized by D. Anderson of Phillips Laboratory.

22. AFOSR Supported Research
Boston, Massachusetts
7/18 - 7/20/91
J.J. Sojka visited the Geophysics Laboratory to discuss collaborative research projects.

23. IUGG General Scientific Assembly
Vienna, Austria
8/16 - 8/22/91
H.G. Demars attended meeting and presented paper.

24. AFOSR Supported Research
Fairbanks, Alaska
9/17 - 9/19/91
L. Zhu visited Joe Kan at the University of Alaska to discuss collaborative research projects.